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ORIGINAL PAPER

Soil chemical properties under modern and traditional farming systems at Khagrachari, Chittagong Hill Tracts, Bangladesh

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Abstract: Land degradation in Chittagong hill tracts has been taking place due to shrinkage of forest cover, policy weakness, population explosion, and inappropriate hill farming system. Modern farming system in the Chittagong hill tracts like Sloping Agricultural Land Technology (SALT) is practiced to provide a new strategy for developing lands for economic productivity and bio-diversity conservation through establishment of ecological community rather than traditional shifting cultivation which is no longer sustainable according to the carrying capacity of ecosystem of Chittagong hill tracts. This study is to find out changing trends of soil chemical properties of sites under modern and traditional farming systems at Khagrachari district of Chittagong hill tracts. The result of the research shows that Sloping Agricultural Land Technology has significantly higher capacity of production due to the presence of the highest percentage of organic carbon, organic matter, compared with shifting cultivated site. The study recommends that shifting cultivation may be changed into a relatively stable semi-permanent farming system through developing participatory integrated farming systems to establish stable production environment in the Chittagong Hill Tracts.

Keywords: sloping agricultural land Technology; sustainable hill farming system; modern and traditional farming system; chemical properties

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Introduction

Hill farming system is an excellent and practically established agricultural production system in accordance with the household's goal and preferences (Shaner et al. 1982). It can be classified as traditional and modern hill farming systems on the basis of past and current practices, but many of them are no longer economically viable and environmentally sound. The practiced modern farming systems in the Chittagong hill tracts are Sloping Agricultural Land Technology (SALT), Chittagong Hill Tracts Multi-sectoral Development Project (CHTMDP), Modern Agricultural Technology (MATH), Contour Hedgerow Intercropping Agro-forestry Technology (CHIAT). Other appropriate technologies for soil conserving farming systems (OATSCF) includes: rain water harvesting, bio-fencing, burning effect, rehabilitation of degraded slopes, landslide hazard management, construction of economic-ecological garden, floriculture, bee-keeping, plastic film technology and gully control and stabilization. Properties of soil macro-nutrients (C, N, K, Ca and P) are increased in degraded hill through different modern hill farming system, e.g., orange cultivation by the *Mro* tribe instead of shifting cultivation in Chittagong hill tracts (Chowdhury et al. 2007a).

Traditional farming systems of Chittagong hill tracts like shifting cultivation, homestead forest and ghona farming have been practicing for many years. The shifting cultivation is the primary occupation and major economic activities of the tribal people living in Chittagong Hill Tracts (Nath et al. 2005). This cultivation system is widely practiced by the tribal people in Chittagong Hill Tracts constituting about 32 500 ha annually (Shoaib et al. 1998). It has been found that 2 163 families in 1964 and 30-35 thousand families in 2002 are involved in shifting cultivation. Shifting cultivation has now become unsustainable (Borggaard et al. 2003) since its cultivation cycle reduced to 2–3-years from 15–20 years. The frequent return of farmers to the same land not only results in a decline in soil yield, but also

reduces biomass production per unit area due to loss of top soil and development of aluminium, manganese and iron toxicities in soil (Arya 2000).

Soil and land of Chittagong hill tracts are not suitable for agriculture. The stock of managed forests of Chittagong Hill Tracts has depleted from 23.8×10^6 m^3 in 1964–1965 to less than 19.8 $\times 10^6$ m^3 in 1985. About 20% of the Chittagong hill tracts region is influenced by shifting cultivation where soils are generally infertile and also 85% of the Chittagong hill tracts are very highly susceptible to erosion (Rahman et al. 2001).

Many problems are associated with the hill farming systems imposed by the environment. The main characteristics of hill farming possess rigorous constraints on production due to its very steep slopes, high precipitation and low temperature. Scientists have been trying to introduce sustainable hill farming systems to discover the erosion control technologies, such as alley cropping, contouring, strip cropping and grass barriers (Poudel et al. 1999; Tacio 1993; Comia et al. 1994; Paningbatan et al. 1995; Presbitero et al. 1995; Sombatpanit et al. 1995). In addition, various researchers and extension agencies have considerable interests on planting of leguminous contour hedgerow trees on sloping lands as barriers for soil erosion in Southeast Asia. However, there is no strong evidence of farmers' adoption of these technologies (Poudel et al. 1999; Fujisaka 1989; Garrity 1993; Comia et al. 1994). Presbitero et al. (1995) reports that soil loss from bare plots is 25 times more than that in plots with multiple cropping of corn and peanut (*Arachis hypogaea*) with *Leucaena leucocephala* contour hedgerows. Soil erosion coupled with productivity decline is considered as a major constraint to sustainable vegetable production in Southeast Asian steep lands. Recently, shifting cultivators are facing food shortage all year, so they are joining participatory forestry programme to improve their livelihood (Nath and Inoue 2009). Because of these problems, many different alternatives are now under considerations and practiced to improve the situation. Sloping Agricultural Land Technology (SALT) is such a technology, which has practiced at experimental level at Alutila of Khagrachari in Chittagong Hill Tracts. This research, therefore, is an attempt, to evaluate changes in soil chemical properties under shifting and SALT cultivated areas at Alutila, Khagrachari.

Materials and methods

Background of the research area

The study area is located at Alutila under Matiranga upazila of the Khagrachari district of Chittagong hill tracts. Chittagong hill tracts development board (CHTBD) has introduced Sloping Agricultural Land Technology (SALT) at Alutila to boost crop yield, soil conservation and fertility. It is one of the programmes of International Centre of Integrated Mountain Development (ICIMOD) at Kathmundu, Nepal. Geologically the area of Alutila comprises hills lying in the physiographic unit of northern and eastern hills. The hills are deeply and closely dissected by V-shaped narrow valleys resulting in the formation of steep to very steep hills with narrow ridges and conical shaped peaks. The hill peaks are about 300 m high above MSL. The orientation of the hill ranges is generally north-north-west to south-south-east. The climate of the area is tropical monsoon. The soils of Alutila SALT demonstration farm have been placed under two groups. i.e., hill soils and valley soils on the basis of physiography, parent material, landform and other pedogenic characteristic. Theses farm soil are mostly belonged to hill soils. Hill soils are developed in the residuum derived from the semi-consolidated sandstones, siltstones and shales of Surma formation of Tertiary age. They are usually brown in colour, acidic in reaction, and loam to silty clay in various textures. Frequent changes in lithology from shale to sandstone and close dissection of the hills with variable slope gradients and aspects provide formation of different soil series. The four soil series namely Barkal, Dhum, Jaldi and Sajek have been recognized in the hills of the study area (Hassan 1999).

Selection of study site

Alutila under Matiranga upazila of Khagrachari hill district is selected as a potential soil sampling area to fulfil the research goal. About 8-year abandoned site without shifting cultivation and 8-year abandoned SALT site with shifting cultivation are sampled at the same slope that might show changes in chemical properties between two different land use systems. Moreover, other two sites, 3-year fallow site preparing for shifting cultivation after burning and 1-year fallow land after shifting cultivation are found at the same slope where we have planned to compare the land capacity through measuring difference in chemical properties of soil. So, four soil sampling sites of the study area are selected on Sloping Agricultural Land Technology (SALT) demonstration plot of Chittagong Hill Tract Development Board (CHTBD). These are: Site 1: 8-year abandoned SALT site without shifting cultivation; Site 2: 8-year abandoned SALT site with shifting cultivation; Site 3: 3-year fallow site prepared for shifting cultivation after burning; Site 4: 1-year fallow site after shifting cultivation. Shifting cultivation is adopted as traditional cultivation and SALT as modern approach in this study. Four soil sampling sites are described (Table 1) as well as the locations of the soil sampling sites are plotted on SALT demonstration area (Fig. 1).

Soil sampling and laboratory analysis

Soil samples are collected at a depth of 0–5 cm, 5–15 cm and 15–30 cm from four sites in triplicate from soil profiles. The sampling of all sites is done at the middle to upper part of the slope having slope gradient of about 55%. Profile characteristics are documented according to standard procedures for four sites. Collected soil samples are analyzed for chemical properties such as soil pH, organic carbon, organic matter, moisture, soil texture, total nitrogen, phosphorus, available potassium and calcium following standard methods in the laboratories of Institute of Forestry and Environmental Sciences and Department of Soil Science, University of Chittagong, Bangladesh. Data analysis is

done statistically to determine variance and Duncan Multiple Range Test (DMRT) ($p≤0.05$) in randomized completely block design using SPSS 10.0 package for comparing the means of soil sampling at different depths under farming systems.

Table 1. Descriptions of the four soil sampling sites at Alutila, Khagrachari

Site No.	Type of soil sampling site	Aspect	Surface coverage	Naturally grown tree species	Slope (%)
Site 1	8-year abandoned SALT site without shifting cultivation	East	Litter (100%); tree (100%); and herbs (50%)	Kanchan (*Bauhinia purpurea*), Rubber, Bogamedula	Steep (30-60)
Site 2	8-year abandoned SALT site with shifting cultivation	West	Annual crop; horticultural and forest species; grass (100%)	Sada Koroi	Steep (30-60)
Site 3	3-year fallow site prepared for shifting cultivation after burning	East	Cleared surface and burned	None	Steep (55)
Site 4	1-year fallow site after shifting cultivation	West	Many flowering plants, few sungrasses and vegetables	Jangli begun, Dumur, Cycas Gamar and Koroi	Very steep (>60)

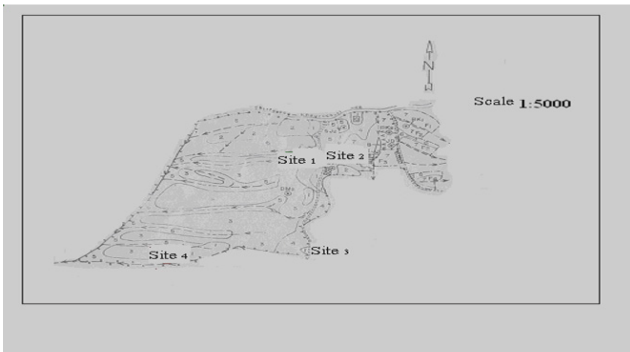

Fig. 1 Location of the soil sampling sites map at Alutila, Khagrachari, Chittagong hill tracts. Site 1: 8-year abandoned SALT site without shifting cultivation; Site 2: 8-year abandoned SALT site with shifting cultivation; Site 3: 3-year fallow site prepared for shifting cultivation after burning; Site 4: 1-year fallow site after shifting cultivation.

Results and discussions

Soil pH

Both moist and dry soil pH values (1: $2H_2O$) are significantly ($p≤0.05$) lower that in Site 1, 2 and 3, compared to Site 4 (1-year fallow site after shifting cultivation). Lower pH in soil of three farming systems is associated with lower content of organic matter. Surface moist soil pH has significantly higher value for 1-year fallow site after shifting cultivation than other three sites. However, pH of air dry soils determined in 1:2 KCl show inconsistency in some cases (Table 2). Continuous cultivation also causes a significant decline in soil pH and exchangeable Ca and Mg levels. This is even more pronounced when acidifying fertilizers are used (Juo and Manu 1996).

Organic carbon (OC) and organic matter

Percentage of organic carbon (OC) and organic matter contents on 1-year fallow site after shifting cultivation, is significantly ($p≤0.05$) lower than that in other three different hill farming systems. These findings indicate that organic matter content is reduced because of continuous shifting cultivation on 3-year fallow site prepared for shifting cultivation after burning. And 1-year fallow site after shifting cultivation has not regained its fertility over one year time. As a consequence, 1-year fallow site after shifting cultivation is a drastically degraded site due to its significant reduction of organic matter that is reflecting the idea of generally sayings by the people that shifting cultivation deteriorates land condition severely. Content of organic matter in SALT abandoned area without shifting cultivation (Site 1) and 8-year SALT area with shifting cultivation (Site 2) suggest that improved farming system such as SALT might keep the land in improved condition (Table 2). A lack of investment in soil restoration has also created the problem of extreme and severe soil degradation by erosion (Lal 1994a) and nutrient depletion (Smaling 1993).

Total nitrogen (N)

Total nitrogen concentration is significantly ($p \le 0.05$) highest on SALT abandoned area with shifting cultivation while lowest significant value is observed on 1-year fallow site after shifting cultivation. Almost similar amounts of nitrogen contents are contained at surface soil of first three farming systems (Table 2). Hanson (1992) reports that among the three billion hectares of arable land in tropical Africa, only 14.7% is considered to be free of physical or chemical constraints. One third (32.2%) has physical constraints, 13.2% has limited nutrient retention capacity, 16.9% has high soil acidity, and 6.8% has high P fixation. Nitrogen and phosphorus are the most serious limiting factors for cereals and food legumes, respectively (Manu et al. 1991; Takow et al. 1991).

Ratio of carbon to nitrogen (C: N)

The C/N ratio is significantly ($p \le 0.05$) highest on site SALT abandoned areas while lowest significant value is found on 1-year fallow site after shifting cultivation. C/N ratio on 3-year fallow site prepared for shifting cultivation after burning is significantly higher among four farming sites at surface soil and soil depth of 5-15 cm due to burning. The burning increases the contents of N, P, K, Ca, Mg and Na in the top soil (Chidumayo 1987) during land preparation for shifting cultivation (Table 2).

Moreover, it may increase N, P and pH and also makes soil nutrients available to the crops immediately and drives away the harmful insects (Okigbo 1984; Seubert et al. 1977). Besides, this makes the ground warm that accelerates germination rate of

naturally fallen seeds e.g. Gamar (*Gmelina arborea*) and Teak (*Tectona grandis*). On the other hand, clearing land through burning for shifting cultivation increases soil erosion. Many scientists have reported that ecological balance is impaired due to the destruction of forests resulted from land clearing for shifting cultivation. Moreover, biomass burning associated with deforestation produces traces gases and increases heating in the atmosphere. Consequently, effect of carbon dioxide may generate possible climate change (Kaufman et al. 1991). It is also reported that burning in shifting cultivation increases 'green house-gases' in the atmosphere while 25% of the total global warming effect is affected from clearing of tropical rain forests (Houghton et al. 1987).

Table 2. Mean values of soil constituents at three different soil depths under different hill farming systems at Alutila, Khagrachari

Soil constituents	Site 1	Site 2	Site 3	Site 4
Mean soil pH (1:2 water) of moist soil	4.78 a	4.61 a	4.80 a	5.65 b
Mean soil pH (1:2 water) of air dry soil	4.74 a	4.72 a	4.62 a	5.33 b
Mean Soil pH (1:2 KCl) of air dry soil	3.93 a b	3.70 a	4.12 b	4.52 c
Mean Organic carbon (%)	2.60 c	2.21 b	2.59 c	1.39 a
Mean Organic matter contents (%)	4.47 c	3.80 b	4.44 c	2.39 a
Mean Total nitrogen (%)	0.22 a	0.23 a	0.20 a	0.19 a
Mean Carbon to nitrogen ratio	12.17 b c	10.03 b	13.22 c	7.40 a
Mean Total nitrogen (%)	0.22 a	0.23 a	0.20 a	0.19 a
Mean Available phosphorous ($g \cdot g^{-1}$ soil)	6.65×10^{-5} b	1.18×10^{-5} a	13.05×10^{-5} c	0.3×10^{-5} a
Mean Available potassium ($g \cdot g^{-1}$ soil)	14.94×10^{-5} a	10.66×10^{-5} a	13.44×10^{-5} a	11.78×10^{-5} a
Mean Available sodium ($g \cdot g^{-1}$ soil)	378.89×10^{-5} a	330×10^{-5} a	380×10^{-5} a	304.44×10^{-5} a
Mean Available calcium ($g \cdot g^{-1}$ soil)	183.33×10^{-5} a	174.44×10^{-5} a	227.78×10^{-5} b	244.45×10^{-5} b
Mean Available potassium ($g \cdot g^{-1}$ soil)	14.94×10^{-5} a	10.66×10^{-5} a	13.44×10^{-5} a	11.78×10^{-5} a

Notes: * Each value is the mean of three replications in the field. Different letters indicate significance differences (p 0.05).

Available phosphorous (P)

The 3-year fallow site prepared for shifting cultivation after burning contains significantly ($p \le 0.05$) higher available phosphorous content, compared to other three different hill farming systems. These results have reflected that available phosphorous contents on 3-year fallow site prepared for shifting cultivation after burning are associated with added material from all the vegetation of the previous time (Table 2). These findings agree with the results found by various scientists, which phosphorous content in the top soil increases through burning (Seubert 1977; Okigbo 1984; Chidumaya 1987). Phosphorous contents are decreased with soil depth in all the farming systems, except for 8-year SALT abandoned area without shifting cultivation.

Available Potassium (K)

Available potassium content is significantly ($p \le 0.05$) lower on 8-year abandoned SALT site (with shifting cultivation), compared to other three farming site (Table 2). Deficiencies of potassium in root crops, sulfur and zinc in maize, and boron in cotton and groundnuts have been reported in continuously cultivated fields which have few or no inputs of crop residues or animal manure (Friessen 1991; Hanson 1992). It is proved that site 2 has the deficiency of potassium nutrients due to continuous shifting cultivation before 8 year. In addition, this site is covered with annual crop, horticultural and forest species and grass (100%). The presence of grass represents that the land is still degraded by the effect of shifting cultivation.

Available sodium (Na)

The 1-year fallow site after shifting cultivation has significantly ($p \le 0.05$) lower available sodium content, compared to other three farming systems (Table 2). As site 3 is covered with flowering plants, few sun grasses and vegetables on very steep slope, so cultivated highly-weathered soils commonly suffer from multiple nutrient deficiencies, and nutrient balances are generally negative (Mokwunye et al. 1996).

Available calcium (Ca)

Significantly ($p \le 0.05$) highest available calcium is found on 3-year fallow site prepared for shifting cultivation after burning, compared to corresponding depth of other three hill farming sites because burning makes more available Ca immediately. Calcium content is significantly lower at 8-year SALT area without shifting cultivation, compared to other three land uses (Table 2) as this site is covered with litter (100%); tree (100%); and herbs (50%) (Table 1). The lack of Ca and PO_4 in many leached tropical soils has, in addition to the nutrient limiting effects on crop growth, also implications on water use efficiency. The scarcity of large mammals in tropical America is attributed to the lack of these two nutrients (Sanchez and Buol 1975). Furthermore, aluminum toxicity and related calcium, magnesium and phosphorus deficiency also limit the growth and yield of cereals and legumes in acid soils of both humid and semi-arid regions (Wilding and Hossner 1989).

Particle size analysis

Soil texture at 1-year fallow site after shifting cultivation and

8-year SALT area with shifting cultivation is sandy, which represents labile and short lived organic matter fraction while other two sites have loamy sand texture indicating the presence of stable and highly mineralized constituents of soil (Table 3). Soil compaction is a serious problem in the tropics, especially in soils containing predominantly low activity clays, high fine sand and silt content, and low levels of soil organic carbon (Kayombo and Lal 1994). Consequently, crop and stand yields are decreased, infiltration capacity of surface crusting is reduced, water and chemical runoff are increased and erosions are accelerated. Soils of low activity clays, high in silt and low content of organic matter in soil, are highly prone to crusting. Calcareous soils are also highly prone to soil crusting. It is a major problem in many soils of tropical America (Roth 1992), Africa (Van der watt and Valentin 1992), Australia (Chartes 1992), and Asia.

Table 3. Textural characteristics (g·g^{-1} air dry soil) at three different soil depth under different hill farming systems at Alutila, Khagrachari

Site No.	Hill farming system	Sand (g·g^{-1})	Silt (g·g^{-1})	Clay (g·g^{-1})	Soil texture
Site 1	8-year abandoned SALT site(without shifting cultivation)	*0.84 a b (4.38)	0.13 a b (3.71)	0.03 a (1.33)	Loamy sand
Site 2	8-year abandoned SALT site (with shifting cultivation)	0.88 a b (3.53)	0.09 a b (0.40)	0.04 a (1.15)	Sand
Site 3	3-year fallow site prepared for shifting cultivation after burning	0.77 a (2.36)	0.15 b (3.53)	0.08 a (2.03)	Loamy sand
Site 4	1-year fallow site after shifting cultivation	0.90 b (3.53)	0.05 a (1.76)	0.05 a (1.76)	Sand

Notes: * Each value is the mean of three replications in the field. Different letters indicate significance differences ($p \leq 0.05$).

Finally, it must be appreciated that there is an important interaction of the causes of soil degradation. Erosion, for example, may be flagged as the major problem, whereas chemical degradation of the soil prevents establishment of vegetation and hence increases the soil erosion. In this example, lack of appropriate vegetation becomes an early warning indicator. Very few studies have been conducted on this linkage between factors, and there is an urgent need to look into this. Land degradation is an important concern affecting the wealth of nations, food security, which is also impacting the livelihood of almost every person on this earth.

There is also the important issue of soil restoration. Soil restoration requires understanding the soil's resilience characteristics and the impacts of exogenous and endogenous factors (Lal 1997; Seybold et al. 1999). The importance of physical management in soil restoration cannot be overemphasized. Despite a considerable body of the literature (Oldeman 1994; Lal 1998), the available research information at plot and hillside scale remains ambiguous, incomplete, inconclusive, and incredible. The problems with the available data are: (i) a failure to adopt standardized methods in monitoring and evaluation (Lal 1994a and b); (ii) lack of basic information relating degree of soil erosion to changes in soil physical properties; and (iii) inadequate data to assess the on-site impact on agronomic productivity. Enrichment ratios of the eroded sediments (for nutrients, clay, and soil organic matter contents), (Zobeck and Fryrear 1986), are rarely determined. Further, most experiments are done on an ad hoc basis, for a short period, without collecting the supporting information on soil profile characteristics, rainfall and wind factors, soil surface properties, or the ground cover.

Conclusions

The sustainability of agriculture in Chittagong hill tracts of Bangladesh is under a serious threat. Development of new agricultural technologies and information of resource management in Chittagong hill tracts would be crucial in meeting the ecological needs and in achieving the anticipated food demands of the growing population in the future. As, land degradation is one of the major concerns in Chittagong hill tracts, so management of soil chemical and nutritional properties are also important to sustain high yields. For example, horticulture cultivation might be one of the alternative ways to protect land degraded area, instead of shifting cultivation (Chowdhury et al. 2007a; Chowdhury et al. 2007b). Government has been trying different hill farming systems in Chittagong hill tracts. While, farmers are motivated to certain hill farming system, infrastructural problems are affecting sustainable management. Various farming systems have different advantages and disadvantages. Policy makers must carefully consider each criterion which can find out potential alternative of sustainable hill farming system. The research output would assist the decision making of soil fertility assurance thorough providing an idea of chemical changes of different land uses are happening due to existing traditional farming system (e.g., 3-year fallow site prepared for shifting cultivation after burning and 1-year fallow site after shifting cultivation) and adopting new alternative hill farming system (SALT with and without shifting cultivation).

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References

Arya LM. 2000. Final consultancy reports on hill agriculture. Agricultural Research Management Projects (ARMP). Gazipur, Dhaka: Bangladesh Agricultural Research Institute.

Borggaard OK, Gafur A, Petersen L. 2003. Sustainability appraisal of shifting

cultivation in the Chittagong Hill Tracts of Bangladesh. Royal Swedish Academy of Sciences. *Ambio*, **32**(2): 118–123.

Chartes A. 1992. Soil crusting in Australia. In: M.E. Sumner and B.A. Stewart (eds.), *Advances in Soil Science*. Boca Raton, FL: Lewis Publishers, pp. 339–365.

Chidumayo EN. 1987. A Jhum Cultivation Land use System under Population pressure in Zambia. *Agroforestry Systems*, **5**(1): 15–25.

Chowdhury MSH, Biswas S, Halim MA, Haque SMS, Muhammed N, Koike M. 2007a. Comparative analysis of some selected macronutrients of soil in orange orchard and degraded forests in Chittagong Hill Tracts, Bangladesh. *Journal of Forestry Research*, **18**(1): 27–30.

Chowdhury MSH, Halim MA, Biswas S, Haque SMS, Muhammed N, Koike M. 2007b. Comparative evaluation of physical properties in soils of orange orchard and bushy forest in Chittagong hill tracts, Bangladesh. *Journal of Forestry Research*, **18**(3): 245–248.

Comia RA, Paningbatan EP, Hakansson I. 1994. Erosion and crop yield response to soil conditions under alley cropping systems in the Philippines. *Soil Tillage Res*. **31**: 249–261.

Friessen DK. 1991. Fate and efficiency of sulfur fertilizer applied to food crops in West Africa. In: U. Mokwunye (ed.). *Alleviating Soil Fertility Constraints to Increase Crop Production in West Africa*. Dordrecht, The Netherlands: Kluwer Academic Publishers, pp. 59–68.

Fujisaka S. 1989. The need to build upon farmer practice and knowledge: reminders from selected upland conservation projects and policies. *Agrofor Syst*, **9**: 141–153.

Garrity DP. 1993. Sustainable land-use systems for sloping uplands in southeast Asia. In: J. Ragland, and R. Lal (eds.), *Technologies for Sustainable Agric. in the Tropics.* Madison, WI: ASA Special Publ, pp. 41–66.

Hanson RG. 1992. Optimum phosphate fertilizer products and practices for tropical climate agriculture. In: *Proc. Int. Workshop on Phosphate* Fertiliz*ers and the Environment.* Alabama, USA: International Fertilizer Development Center, Muscle Shoals, pp. 65–75.

Hassan M. 1999. *Soils of Bangladesh: their genesis, classification and use potentials*. Narinda, Dhaka: The March Printers.

Houghton RA, Boone RD, Fruci JR, Hobbie JE, Melillo JM, Palm CA, Peterson BJ, Shaver GR, Woodwell GM, Moore B, Skole DL, Myers N. 1987. The flux of carbon from terrestrial ecosystems to the atmosphere in 1980 due to changes in land use: geographic distribution of the global flux. *Tellus*, *39B*: 122–139.

Juo ASR and Manu A. 1996. Chemical Dynamics of Slash and Burn Agriculture. *Agriculture*, *Ecosystems and Environment*, **58**(1): 49–60.

Kaufman YJ. Robert SF, Robert LM. 1991. Fossil Fuel and Biomass Burning Effect on Climate—Heating or Cooling? *J. Climate*, **4**: 578–588.

Kayombo B, Lal R. 1994. Response of tropical crops to soil compaction. In: B.D. Soane and C. Van Ouwerkerk (eds.). *Soil Compaction in Crop Production*. Amsterdam: *Elsevier*, pp. 287–315.

Lal R. 1994a. Global overview of soil erosion. In: *Soil and Water Science*: Key to Understanding Our Global Environment. Madison, WI: Soil Sci. Soc. Am. Special Publ., No. **41**, pp. 39–51.

Lal R. 1994b. Soil erosion by wind and water: Problems and prospects. In: R. Lal (ed.). *Soil Erosion Research Methods*. Ankeny, IA: Soil Water Conservation Society, p. 282.

Lal R. 1997. Degradation and resilience of soils. *Phil Trans R Soc Land B*, **352:** 997–1010.

Lal R. 1998. Soil erosion impact on agronomic productivity and environment quality. *Crit Rev Plant Sci*, **17**(4): 319–464.

Manu A, Bationo A, Geiger SS. 1991. Fertility status of millet producing soils of West Africa with emphasis on phosphorus. *Soil Science*, **152**: 315-320.

Mokwunye AU, Jager Ade, Smailing EMA. 1996. *Restoring and maintaining the productivity of West Africa Soils: Key to sustainable development.* International Fertilizer Development Center (IFDC), Alabama: Muscle Shoals, p. 94.

Nath TK, Inoue M, Myant H. 2005. Smallscale agroforestry for upland community development: a case study from Chittagong Hill Tracts, Bangladesh. *Journal of Forest Research*, **10**: 443–452.

Nath TK, Inoue M. 2009. Forest-based settlement project and its impacts on community livelihood in the Chittagong Hill Tracts, Bangladesh. *International Forestry Review*, **11**(3): 394–407.

Okigbo BN. 1984. Improved permanent production systems as an alternative to shifting intermittent cultivation. In: *FAO Soil Bull. No*. **53**. Rome: FAO, pp. 1–100.

Oldeman LR. 1994. Global extent of soil degradation. In: D.J. Greenland and I. Szabolcs (eds.). *Soil Resilience and Sustainable Land Use*. Wallingford, UK: CAB Int. Oxon, GB, pp. 99–118.

Paningbatan EP, Ciesiolka CA, Coughlan KJ, Rose CW. 1995. Alley cropping for managing soil erosion of hilly lands in the Philippines. *Soil Technol*, **8**: 193–204.

Poudel DD, Midmore DJ, West LT. 1999. Farmer participatory research to minimize soil erosion on steepland vegetable systems in the Philippines-agriculture. *Ecosystems and Environment*, **79**: 113–127

Presbitero AL, Escalante MC, Rose CW, Coughlan KJ, Ciesiolka CA. 1995. Erodibility evaluation and the effect of land management practices on soil erosion from steep slopes in Leyte, the Philippines. *Soil Technol*, **8**: 205–213.

Rahman MM, Mostafa G, Razia SW and Shoaib JU. 2001. Land degradation in Bangladesh. In: E.M. Bridges, I.D. Hannam, L.R. Oldeman, F.W.T. Penning de Vries, S.J. Scherr and S. Sombatpanit. (eds.), *Response to Land Degradation.* New Hampshire, USA: Science Publishers, pp.117–129.

Roth CH. 1992. Soil sealing and crusting in tropical South America. In: Soil Crusting: Chemical and Physical Processes. M.E. Sumner and B.A. Stewart (eds.). *Advances in Soil Science.* Boca Raton, FL: Lewis Publishers, pp. 267–300.

Sanchez P A and Buol SW. 1975. Soils of the tropics and world food crisis. *Science*, **188**: 598–603.

Seubert CE, Sanchez PA, Valvarde C. 1977. Effects of Land Clearing Methods on soil Properties of an Ultisols and crop performance in the Amazan Jungle of Peru. *Tropical Agriculture*, **54**: 307–321.

Seybold CA, Herrick JE, Brejda JJ. 1999. Soil resilience: A fundamental component of soil quality. *Soil Sci*, **164**: 224–234.

Shaner WW, Philipp PF, Schmehl WR. 1982. *Farming System and Research and Development: Guidelines for developing countries*. Boulder: Westview Press, pp.1–39.

Shoaib JU, Mostafa G, Rahman M. 1998. *Soil erosion hazard in Chitttagong Hill Tracts: a case study. Annual Report 1998*. Dhaka: Soil Resources Development Institute.

Sombatpanit S, Rose CW, Ciesiolka CA, Coughlan KJ. 1995. Soil and nutrient losses under rozelle (Hibiscus subdariffa L. var. altissima) at Khon Kaen. Thailand. *Soil Technol*, **8**: 235–241.

Tacio HD. 1993. Sloping agricultural land technology (SALT): a sustainable agroforestry scheme for the uplands. *Agrofor. Syst.*, 22: 145–152.

Takow JA, Doumbia MD and Hossner LR. 1991. Acid soils profiles of the semiarid and subhumid tropics in Central and West Africa. In: *Plant-Soil Interactions at Low pH*. The Netherlands: Kluwer Academic Publishers, pp. 313–320.

Van der Watt, Valentin C. 1992. Soil Crusting: the African view. In: M.E. Sumner and BA Stewart (eds.). *Soil Crusting: Chemical and Physical Processes.* Boca Raton FL: Lewis Publ, pp. 301–338.

Wilding LP, Hossner LR. 1989. Causes and effects of acidity in Sahelian soils. In: *Soil*, *Water and Crop Management in the Sudano-Sahelian Zone.* Patancheru, India: ICRISAT, pp. 215–227.

Zobeck TM and Fryrear DW. 1986. Chemical and physical characteristics of windblown sediment. II. Chemical characteristics and total soil and nutrient discharge. *Trans. ASAE*, **29**: 1037–1041.